Feature Article

Electrodialysis Membrane Technology for Purification of Brackish Ground Water

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Abstract

Experimental results for the feed and the product water taken from a model village (Kusugal) in Dharwad district are presented using the indigenously developed electrodialysis membranes. The quality of feed water before electrodialysis indicates extremely high levels of hardness, but a tremendous improvement occurred when the feed water was subjected to electrodialysis process. The product water was continuously monitored at regular intervals of time to understand the working of the unit. These data are tabulated and the effectiveness of the present technique over the conventional membrane-based techniques has been discussed. The cost-effectiveness and the viability of the method for the treatment of water in similar other brackish zones are also discussed. A tremendous decrease in the hardness, alkalinity, acidity and total dissolved salts was observed.

Keywords

Electrodialysis, ion exchange membranes, reverse osmosis

Introduction

Among many membrane-based separation processes (MBSPs), electrodialysis (ED) is one of the most versatile techniques that has been used as an effective method to remove the unwanted excessive salts from brackish ground water sources to get potable water.[1,2] In this method, an electrical potential gradient is applied across the ion-exchange membranes in order to separate the ions from brackish water. In a typical ED experiment, the anion and cation exchange membranes are arranged alternatively and when electric current is applied, the cations migrate towards the negative electrode and vice versa. As a result, ions in the alternative compartments are depleted so as to get the product (diluate) as potable water. In addition, ED can also be used to recover the valuable metals from industrial effluents, to remove salts and acids from pharmaceuticals as well as to produce salt from sea water.

Due to various reasons including excessive pumping of water in several rural regions, the quality of ground water has deteriorated i.e., it has become brackish with increasing hardness. The dangers of chloride and fluoride contamination in water has been already noticed in many areas. Several thousands of people in India have been affected by fluorosis due to excessive fluoride in water and this has been the cause of premature aging of bones and teeth. The excessive pumping of ground water in West Bengal (India) has caused lowering of ground water level. This has enabled air to seep through the ground and oxidized arsenic into more dangerous and leachable arsenate resulting in arsenic poisoning in several districts of West Bengal. The excess of nitrate in ground water is due to increase in the application of artificial fertilizers used in agricultural fields, which ultimately seeps down to the drinking water wells. Recent studies have clearly shown a direct correlation between the intake of nitrate and blue baby syndrome (resulting in infant mortality), cancer of the womb and other problems in pregnant women. Excessive chloride has recently caused panic in some villages of Gujarat State (India) where young and capable people have suddenly developed premature aging symptoms requiring walking sticks to move around. Most of other diseases like Diarrhea and Amoebiasis are also caused by the polluted water and hence, the infant mortality rates in rural areas are alarmingly high. Excessive salt intake also causes kidney stone, ureteric, gall stone and blood pressure apart from a host of other complications.

In order to circumvent the above stated problems and to provide good quality water to the rural people, recently we have undertaken a detailed study on the development and application of ED technology. The laboratory level research has been culminated into a large scale application. In this paper, the experimental results are presented for treating brackish water from a nearby village (Kusugal) in the district of Dharwad using the ED technique. The unit produces nearly 15,000 liters of potable water for every 8 h. The ED principles in addition to process parameters like flux, water quality, technical feasibility and economics of the method as well as operational conditions have been studied. Furthermore, advantages of the use of ED technique over other MBSPs have been discussed.

Principles of Electrodialysis

Even though the principle of ED is known for more than 60 years, its large scale industrial application did not occur until the development of multi-cell stack design and the efficient ion-exchange membranes with high selectivity, low electric resistivity, good chemical and mechanical stability. The basic principles of ED will be reviewed here briefly.

In an ED unit, the anion and cation exchange membranes are alternatively arranged. Feed water is allowed to pass between alternate chambers formed by anion and cation membrane pairs. At the end of the stack of membrane pairs, anode and cathode are placed inside the plastic electrode housing. The DC is applied between these electrodes to enable the anions and cations to migrate towards anion and cation exchange membranes respectively. These ions selectively permeate through the membrane and come out at the adjacent chambers, where they get concentrated, forming a concentrated stream. The electrical energy required is proportional to the concentration of salt in the saline water. The schematics of the method is illustrated in Figure 1.

The ionic movements and the resulting demineralization in the electrodialysis process is presented schematically in Figure 2.

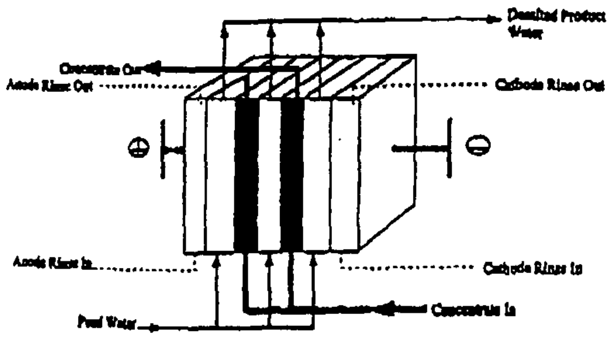
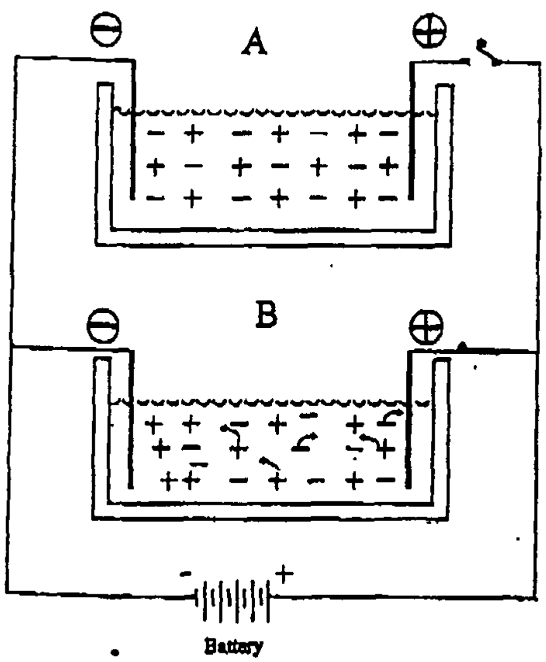


Figure 1.

In ED, there are two streams: one for brine solution which carries concentrated ions and the other for product water which has less number of ions. Several hundreds of cell pairs of this type are placed in stacks so that a considerable amount of current can be carried. When the ED unit is in operation, feed water passes in parallel paths through all of the cells providing a continuous flow of product water and brine.

The movement of ions in ED can be discussed by the schematic diagrams given in Figure 2.

- Figure 2A: Here, the typical ions like Cl^-, Na^+, HCO_3^-, Mg^{2+}, SO_4^{2-} and Ca^{2+} are produced from the ionization of salts that make water brackish. These ions attract the dipolar water molecules and diffuse uniformly throughout the solution.
- Figure 2B: The two electrodes are placed in solution containing the ions and when the electric current is switched on, these ions migrate towards the oppositely charged electrodes.
- Figure 2C: The ion selective membranes are placed alternatively so that the oppositely charged ions migrate and these are then trapped between the alternate cells. A positively fixed charge (anionic) membrane allows only negative ions to transport, but repels the positive ions. A negatively fixed charge (cationic) membrane allows only positive ions to transport, but repels negative ions.
- Figure 2D: If the above process continues, almost all of the ions get trapped in the alternate cells. This leads to the depletion of ions and thus exhibits high resistance to flow of current.
- Figure 2E: This displays the overall process of ED. When the feed water enters both the concentrate and product cells, almost all the ions in the product cells migrate and are trapped in the concentrate cells. This leads to two streams emerging from the device: one having the concentrated brine solution and the other with a much lower concentration of TDS (product water).



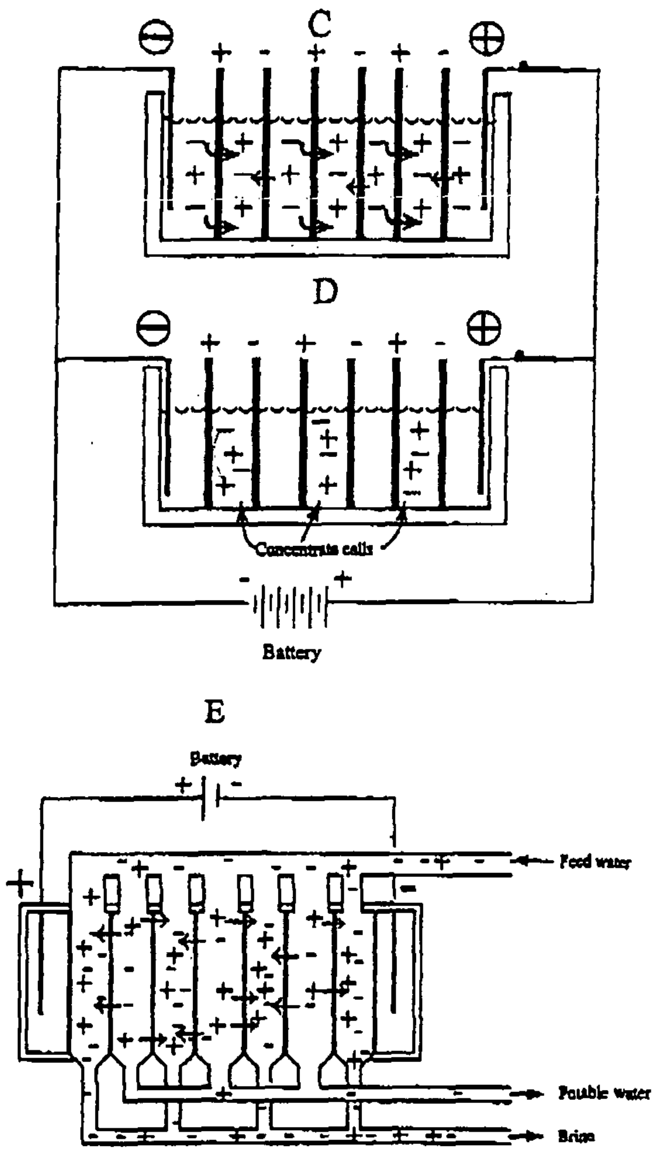


Figure 2.

In a single pass operation, the feed flow is controlled to get the desired quality product water. In a batch mode operation, feed water is taken in a tank and recirculated through the dilute chamber until the concentration of dissolved salts reduces to the desired level. The anode and cathode rinse continuously to remove the gases liberated at the electrode surfaces. Generally, in a brine solution containing sodium chloride, chlorine is liberated in the anode chamber and hydrogen is liberated in the cathode chamber. In a practical ED system, nearly 200 to 400 cation and anion exchange membranes are installed in parallel to form an ED stack with 100 to 200 cell pairs as shown in Figure 1.

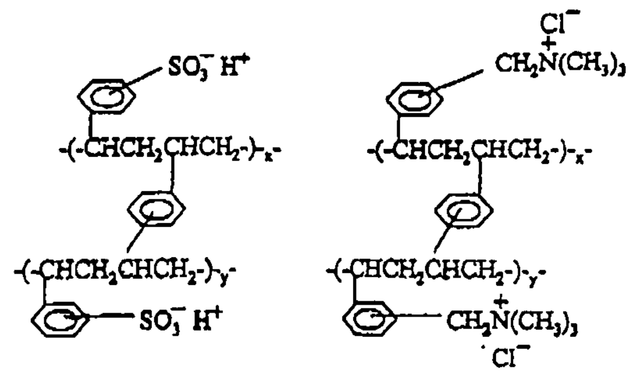
The process parameters such as membrane properties, energy requirements, description of the main components of a plant and cost analysis are very important and these will be discussed later. In all the ED operations, membranes are the most important components. The type of membranes used and their methods of preparation are given below.

Preparation of Ion Exchange Membranes

Ion exchange membranes are the synthetic polymeric sheets made up of organic ion exchange resins. These membranes should have high selectivity for the oppositely charged ions, low electric resistance, good mechanical strength, good chemical stability and low degree of swelling. The anion exchange membranes contain cationic groups fixed to the main polymer matrix and these fixed cations are in electrical equilibrium with the mobile anions in the interstices of the resin. When such a membrane is immersed in an electrolytic solution anions in the solution can intrude into the resin matrix and replace anions present initially, whereas the cations are prevented from entering the matrix by the repulsion of the cations fixed to the resin. The cation exchange membranes work similarly. They contain fixed anionic groups that permit intrusion and exchange of cations from an external source, but exclude anions. This is called as Donnan exclusion. Methods of making ion exchange membranes have been described in detail in the literature.[7]

There are basically homogeneous and heterogeneous ED membranes. The heterogeneous membranes are prepared by incorporating ion exchange particles into film-forming resins by: (a) dry molding or calendering mixtures of the ion exchange and film-forming materials, (b) dispersing the ion exchange material in a solution of the film-forming polymer, then casting the films from the solution and evaporating the solvent and (c) dispersing the ion exchange material in a partially polymerized film-forming polymer, casting films and then completing the polymerization. The heterogeneous ion exchange membranes have several advantages, the most important of which are relatively high electrical resistance and poor mechanical strength when highly swollen in dilute salt solutions. Homogeneous ED membranes have significantly better properties because fixed ion charges are distributed homogeneously over the entire polymer matrix. The chemical structures of typical ion exchange membranes are given below.

In the cation exchange membrane the sulphonate groups are chemically bonded to most of the phenyl groups in polystyrene. The negative charges of the sulphonate groups are electrically balanced by the positively charged cations and these ions act as counterions. The sulphonated polystyrene swells greatly in water and this swelling is controlled by using divinylbenzene as the crosslinking agent in the polymer. The positively charged counter ions are appreciably dissociated from the bound so that the negatively charged groups get imbibed in which they are mobile. Then these will be exchanged with other cations by maintaining the electrical neutrality of the membrane and thus help to carry the electrical current. Similarly, in the anion-exchange membrane, polystyrene is crosslinked with divinylbenzene and the positively charged quaternary ammonium



Cationic exchange membrane Anionic exchange membrane

Figure 3. Schematic representation of ion exchange membranes

Table 1. Some physical property data of ED membranes

Property	EDM-C[a]	EDM-A[b]
Resistance (ohms-cm^2)	2–4	6–10
Transport Number	>95	>94
Capacity (T-Na$^+$)	1.8–2.0	1.8–2.0
Thickness	0.10–0.15	0.10–0.15
Burst Strength (kg/cm^2)	2.0–2.5	2.0–2.5
Moisture (%)	25–30	18–20

[a] EDM-C → Strongly acidic cation exchange membrane
[b] EDM-A → Strongly basic anion exchange membrane

groups are chemically bonded to phenyl groups of polystyrene. In this case, the positively charged quaternary ammonium groups are electrically balanced by the negatively charged anions and these ions will help to carry the electric current. Table 1 compiles the required properties for the ED membranes.

Advantages of Electrodialysis

Electrodialysis is a membrane-based separation technique for separating inorganic ions in which DC is used as a driving force. The method is widely used in desalting saline water having salt content of 1 g/L to 15 g/L and bring the salt content down to potable water limits of 0.5 g/L or even less. The World Health Organization (WHO) has set the upper limit of salt content in drinking water to 0.5 g/L. In India or elsewhere, where the arid or semi-arid regions of the plains, deserts and brackish water regions in coastal belts have the problem of brackish water, the cheapest method of desalting and purifying salt water is by ED. The other competitive method to ED is reverse osmosis (RO). But RO is much costlier for brackish water desalination because it requires high pressure pumps, fittings and more stringent pretreatment of feed water. Also, the membrane life of RO is 1 to 2 years, while the life of ED membrane is 4 to 5 years. The ED does not need costly pretreatment or high-pressure pumps. For small portable ED units, capable of desalting 100 to 300 liters/day, there is no necessity to use any pumps. An overhead tank of 10 to 12 feet is sufficient to provide the pressure necessary to force the feed

water to pass between the membranes. The ED unit thus requires DC electricity of 12 volts and above to operate the system. Therefore, the conventional DC rectifiers, solar photovoltaic panels or even storage batteries can be used to operate the ED system, making it the most efficient, economical and easiest-to-operate desalination system.

Of the various techniques developed for water purification, ED is one of the most ideal ones. It has the following advantages over other systems, making it most suitable for rural areas.

- Easy to maintain with minimum maintenance cost compared to RO or any other MBSPs.
- Low consumption of electricity 2 to 4 kW/h (i.e., units of electricity) to produce 1,000 liters of pure water. This amount of water can be produced in 30 min.
- Can be installed and operated in villages not having electricity, because the ED units can be directly operated with load-matched photovoltaic (diesel) panels.
- Low initial investment cost is required. For instance, the unit installed at Kusugal costs Rs. 400,000 i.e., at the rate of Rs 40 per US $ it works out to be 10,000 US $.
- Long life of more than 10 years for the plant and 5 years for the membranes compared to 1–2 years for RO membranes.
- Pretreatment cost of raw feed water is minimal compared to RO and silt density index restriction is not applicable.
- Can be operated up to 50 °C in the pH range of 2–10.
- Removes up to 90% of the salt from brackish water and recovers 80–90 liters of good water from 100 liters of brackish water.
- Chlorine dosed water does not affect the membranes and frequency of membrane cleaning is less than RO.
- Ideally suited for treating brackish water containing 5,000 mg/L of TDS.
- Removes minerals, fluoride, nitrate and heavy metals from the brackish water.
- Membrane fouling in ED is much less compared to RO membranes and manual scrubbing can clean the membranes unlike RO membranes. Membrane cleaning can be done with 10% HCl.
- DC power supply/storage battery/solar cells can drive the system.

Design of the Plant

The production of potable water from brackish water depends upon the extent of hardness of ground water. Therefore, the capacity and size of the plant is a function of the quality of water to be treated. For example, 20,000 liters of potable water can be produced if the total dissolved salts (TDS) ranges between 1,500 and 2,000 ppm (i.e., 15–20 g/L of dissolved salt in water). For instance the plant installed at Kusugal has the capacity to produce about 15,000 liters of potable water for 8 hours of duration. The flow sheet of the unit is given in Figure 4. The actual photographs of the ED unit installed in Kusugal are shown in Figure 5.

The plant has the following dimensions.

- ED unit size: (600 mm × 1,100 mm × 800 mm)
- Membrane size: (500 mm × 1,000 mm)
- Electrode housing: (1,000 mm × 500 mm, 2 numbers)
- Cation and anion membrane pairs: (120)
- Gaskets: (500 mm × 1,000 mm)
- Spacers: 880 mm × 380 mm
- Precious metal coated titanium anode size: (880 mm × 380 mm)
- Stainless steel cathode size: (880 mm × 380 mm)
- Pressing assembly and frame

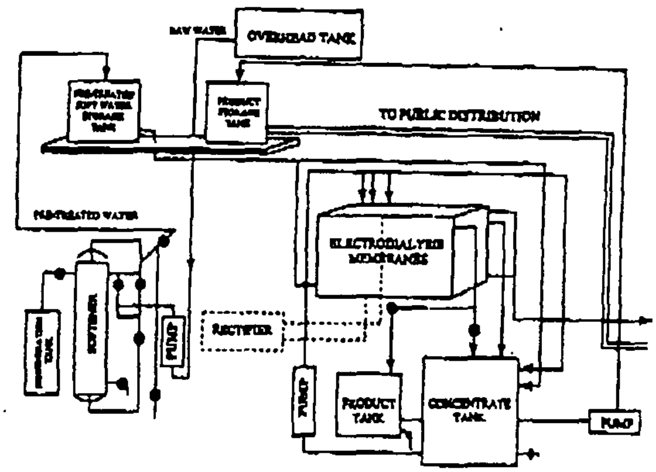


Figure 4. Flow sheet diagram of ED unit installed in Kusugal

- 230 volt DC with 15 amps capacity power supply
- Two pumps of 0.5 HP capacity for circulation of feed water and concentrate stream
- One pump of 0.25 HP capacity for circulation of electrode wash
- Rotameter (flow indicator and control), solenoid valve, ball valves, pipe line and panel board.

Economics

The cost of a ED unit depends upon the feed water composition and its salinity. Some feed solutions may require a significant amount of pretreatment while other feed solutions can be processed without any chemical treatment. For feed solutions with low salinity, chemical treatment along with the general maintenance and operating costs may become a significant portion of the total operating cost. The total cost of the plant works out to be nearly Rs. 400,000 as detailed below.

Cost of electricity:	Rs. 150=00/day for 20,000 liters product water
Cost of capital recovery factor:	Rs. 215=00/day for 20,000 liters product water (based on 15% interest and capital recovery in 10 installments)
Total expenditure/day:	Rs. 3=65/day for energy and capital recovery
Cost of water produced:	3–4 Paise/liter

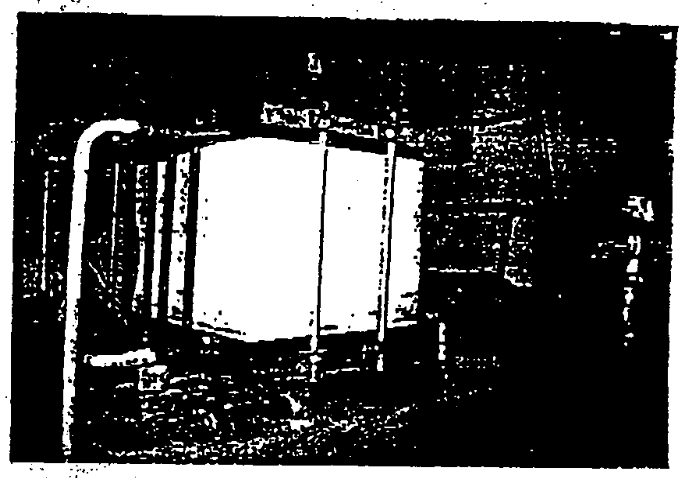
Cost of ED plant of 20,000 liters/day is given below.

Feedwater quality (ppm)	Plant cost (in Rupees)
1500	2,75,000 = 00
2000	3,25,000 = 00
2500	3,75,000 = 00
>2500	4,00,000 = 00

Mr. Rajneesh Goel and Mrs Shalini Goel

Dr. Mahadevappa and Dr. Aminabhavi

Installed overhead tank



Assembled ED unit

Fig. 5 Actual photographs of the ED unit installed in Kusugal village

Cost of water produced (for 2,000 ppm and 20,000 liters per day) is detailed below:

Cost due to electricity	Rs. 150/day (@ Rs. 3/unit)
Cost due to interest	Rs. 160/day (@ 15% interest)
Cost of capital recovery	Rs. 108/day (10% return/year)
Total cost	Rs. 418/day for 20,000 liters
Cost of water produced	3–4 Paise/liter

(Please note the exchange rate 1 US $ = Rupees 40 and 1 Rupee = 100 Paise)

Actual Field Data on the Installed ED Plant in Kusugal

One ED plant was set up in Kusugal village under the sponsorship of Zilla Panchayat, Dharwad. This unit was installed in November 1998 and the unit is successfully operating which provides potable water to villagers. The ground water quality data before treatment are given in Table 2. The treated water data are compiled in Table 3. From these results it is observed that the plant is successful in reducing the hardness and TDS of water meeting the standards of the WHO limit. From a perusal of the raw water data, it is important to pretreat water before it is sent to ED membrane stacks. An amount of 20 kg of salt is to be added for pretreatment three times in a week.

Applications of Electrodialysis

- Desalting of brackish water and seawater to get potable water.
- Desalination of municipal sewage treated water and tertiary processing of sewage.
- Industrial wastewater treatment for reuse of water, especially in electroplating, tannery, dyeing, semiconductor, printed circuit board and mining industries.
- Treatment of RO reject stream for further concentration and water recovery.

Table 2. Brackish water data in Kusugal village from three borewells and their mixtures before treatment

Test	WK-1 24-9-98	WK-2 25-9-98	WK-3 26-9-98	WK-4 25-10-98	WHO Limits
Acidity (ppm)	63.0	31.5	70.8	86.6	250
Alkalinity (ppm)	369.7	258.4	393.5	385.8	250
Chloride Content (ppm)	1378.4	1086.0	1099.8	1099.9	250
Hardness (ppm)					
Ca^{2+}	796.3	642.2	711.9	667.9	
Mg^{2+}	348.6	499.1	528.4	601.4	
Total	1144.9	1141.3	1240.3	1269.3	500
TDS (ppm)	5130	3490	4030	3910	1000
pH	8.3	7.7	8.3	7.3	6.5–8.5
Nitrate Content (ppm)					
NO_3	>350	>350	>350	>350	45

WK-1–Direct water from borewell no. 1
WK-2–Direct water from borewell no. 2
WK-3–Mixed water from all borewells and sent to overhead tank
WK-4–Direct water from borewell no. 3

Table 3. Product water data in Kusugal village after treatment

Test	WK-P 14-11-98	WK-P 24-11-98	WK-P 4-12-98	WK-P 14-12-98	WK-P 24-12-98	WHO Limits
Acidity (ppm)	29.5	39.35	27.22	54.1	51.2	250
Alkalinity (ppm)	94.4	106.65	98.96	167.6	155.2	250
Chloride Content (ppm)	167.1	189.85	131.0	121.2	204.6	250
Hardness (ppm)						
Ca^{2+}	9.1	45.9	100.1	111.1	40.4	
Mg^{2+}	27.6	64.2	127.6	142.1	50.5	
Total	36.7	110.1	238.5	253.2	90.9	500
TDS (ppm)	310	441	449	332	210	1000
pH	7.7	7.7	7.2	7.26	7.17	6.5–8.5
Nitrate Content (ppm) NO_3	40.5	36.4	30.9	31.5	28.7	45

WK-P–Product water after electrodialysis

- Deashing of sugar cane juice for production of better quality sugar and improved yield with reduced generation of molasses.
- Deacidification of fruit juices, especially grape, orange etc. for enhanced shelf life.
- Purification of chemicals, especially separation of inorganics from organic liquids and selective separation of valuable inorganic metals from aqueous medium.
- Purification of amino acids, vitamins, enzymes and vaccines.

The most important large scale application of ED is in the production of potable water from brackish water. Here, ED is competing directly with RO and multi-stage flash evaporation. For water with relatively low salt concentration i.e., < 5,000 ppm, ED is the most economic process. However, the most significant feature of ED is that salts can be concentrated to high values i.e., in excess of 18 to 20 wt % without affecting the economics of the process severely. Because of this, ED is also used (mainly in Japan) to produce salt from sea water. In waste water treatment, the complete recycling of water and metal ions is achieved by ED because it has the advantages of utilizing thermally and chemically stable membranes so that the process can be run at elevated temperatures as well as in acidic or basic solutions. In addition, other successful applications of ED have been studied on a laboratory scale in food, dairy, chemical and drug industries, but large-scale commercially operated plants are still rare at present.

Concluding Remarks

In India, several regions are facing acute brackish water problem i.e., water has become unfit for drinking due to various reasons including excessive pumping, seawater, ingression etc. Also, the problem of excessive fluoride, chloride, hardness etc., has been found in certain pockets of India. Some of the identified areas include the regions of north Karnataka, coastal belts of Gujarat, Andhra Pradesh, Tamil Nadu, Kerala, Surendranagar, Bhavnagar, Ahmedabad and Western Regions of Gujarat and Rajasthan. Also, water problem has been

encountered in some of the islands of Indian territory. Most of the commercially available water purification units do not remove the dissolved inorganic salts which are harmful for human consumption. The recently introduced RO units are expensive and require costly maintenance and they are easily susceptible to membrane fouling. In order to circumvent some of the above mentioned problems, we are able to develop small scale domestic ED units to provide a solution in the areas facing brackish water problem. The unit removes the excessive inorganic salts and helps to reduce the incidence of kidney stones, fluorosis etc. The ED units are easy to operate and consume very little electricity. The energy consumption is only about 0.3 unit of electricity i.e. about 90 paise for getting 100 liters of desalted water (based on Rs. 3 per unit). This works out to be about 3–4 paise per liter of purified water and this water conforms to the standards set by WHO. Presently, more work is under progress to take up this project for other villages in Gadag districts.

Acknowledgments

We are thankful to Mr. Rajneesh Goel, Deputy Commissioner, Dharwad district and Mrs. Shalini Goel, Chief Executive Officer, Zilla Panchayat, Dharwad district for their encouragement and financial support. This unit was installed under the auspices of Dr. S. Rame Gowda Institute of Science and Technology, Dharwad.

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Meetings/Calendar of Events

May 2000

S	M	T	W	T	F	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

May 1–5, 2000. Frontiers of Polymer Science & Polymer Engineering, Akron Ohio. Contact: Nancy Clem, The University of Akron, College of Polymer Science & Polymer Engineering, Akron, Ohio 44325-3909 Tel: (330) 972-8625 or clem@uakron.edu

May 7–11, 2000. 58th Annual Technical Conference & Exhibition (ANTEC), Orlando, FL. Contact: Society of Plastics Engineers, 14 Fairfield Dr., Brookfield, CT. Tel: 203/740–5452. Fax: 203/740–2671.

May 10–11th, 2000, Particle Foam 2000, Wiesloch/Heidelberg, Germany. Contact: VDI Verein Deutscher Ingenieure, VDI-Gesellschaft Kunststofftechnik, Postfach 10 . 39, 40002 Düsseldorf, Germany, Phone: **49/211/62 14-527, Fax: **49/211/62 14-0, e-mail: kunststoffe@vdi.de

May 11, 2000. Principles of Polymer Blending and Alloying, Orlando. Contact: Society of Plastics Engineers, World Headquarters, 14 Fairfield Drive, Brookfield, CT 06804–0403 USA, Phone (203) 775–0471, Fax (203) 775–8490, http://www.4spe.org

May 11–12, 2000, Plastics Processing and Manufacturing, Williamsport PA. Contact: Plastics Manufacturing Center, Pennsylvania College of Technology, One College Avenue, Williamsport, PA 17701, (570) 321–5533, Fax (570) 327–4529

May 14–16, 2000. The Society of the Plastics Industry's Fluoropolymers Division. Fluoropolymers—The Material for the New Millennium, Maui Hawaii. Contact: SPI Fluoropolymers Division, 1801 K Street NW, Suite 600K, Washington, DC 20006–1301; (202) 974–5234.

May 15–19, 2000. Polymer Chemistry for Coatings, Rolla Missouri. UMR Coating Institute, Contact: Alice M. Clift Coordinator, Department of Chemistry, Bureau of Mines Bldg. #2, 1870 Miner Circle, Rolla, MO 65409–1020, Tel: (573) 341–4419, Fax: (573) 341–4881, e-mail: coatings@umr.edu

May 15–19, 2000. Composite Structures: Fabrication & Damage Repair, Reno, NV. Contact: Abaris Training Resources, Inc., 5401 Longley Lane, Suite 49, Reno, NV 89511 USA, Tel: (800) 638–8441, (775) 827–6568, Fax: (775) 827–6599, http://www.abaris.com

May 21, 2000. Intensive Short Course—Flame Retardancy of Polymer Materials, Stamford CT. Contact: Mr L. Naturman, Business Communications, 25 Van Zant St, Stamford CT. Tel: 203-853-4266.

May 21–25, 2000, SAMPE 2000, Long Beach, CA. Contact: SAMPE, P.O. Box 2459, Covina, CA 91722, Phone: 626/331–0616 ext. 603, Fax: 626/332–8929, E-Mail: 102022.3113 @compuserve.com

May 22–24, 2000, Recent Advances in Flame Retardancy of Polymeric Materials, Stamford CT. Contact: Prof Menachem Lewin, Polytechnic University, 6 Metrotech Center, Brooklyn, NY. Tel: 718-260-3163.

May 22–24, 2000. Sixth International Conference on Computer Aided Assessment and Control. Site: Montreal, Quebec, Canada. Contact: Conference Secretariat, Damage and Fracture Mechanics 2000, Wessex Institute of Technology, Ashurst Lodge, Ashurst, Southampton, SO40 7AA, UK. Telephone: +44 (0) 23 80 293223; fax: +44 (0) 23 80 292853; or e-mail: wit@wessex.ac.uk

May 22–24, 2000. Low Frequency Soft Magnetic Material Conference, Dearborn, Michigan. Contact: Deborah Crommett at Intertech Conferences, 19 Northbrook Drive, Portland, Maine, 04105 USA; Telephone +(207)–781–9800, Fax: +(207) 781–2150, Email: deborahc@intertechusa.com.

May 22–25, 2000. Introduction to Powder Coatings Technology, Hattiesburg MS. Contact: USM Polymer Coatings, Shelby F. Thames, Director, The University of Southern Mississippi,Box 10037, Hattiesburg, MS 39406–0037, Tel: 601-266-5618 or 601-266–4080, Fax: 601-266-5880, E-mail: Shelby.F.Thames@usm.edu